2017 DOE BETO Algae Platform Review
Project # 1.3.5.100

Dr. Gary Dirks (PI) and
Dr. John McGowen (Presenting)
Dir. of Operations and Program Management
Arizona State University
March 8, 2017

One little cell,
a world of
possibilities.

ATP3
Algae Testbed
Public-Private Partnership

U.S. DEPARTMENT OF ENERGY

ATP3
Algae Testbed
Public-Private Partnership

Acknowledgements

ASU
Gary Dirks
John McGowen
Thomas Dempster
Pete Lammers
Milt Sommerfeld
William Brandt
Jessica Cheng
Sarah Arrowsmith
Sarah Kempkes
David Cardello
Theresa Rosov
Maria Bautista
Mary Cuevas
Richard Malloy
Henri Gerken
Pierre Wensel
Linda Boedeker
Jamie Rock
Sarah Mason
Travis Johnson
Sydney Lines

UTEX
Schonna Manning
Jerry Brand

Valicor Renewables
Kiran Kadam
Brian Goodall

NREL
Phil Pienkos
Lieve Laurens
Eric Knoshaug
Ed Wolfrum
Ryan Davis
Christopher Kinchin
Stefanie Van Wychen

Sandia National Labs
Ron Pate
Todd Lane
Kunal Poorey
Patricia Gharagozloo
Thomas Reichardt
Jeri Timlin
Jessica Drewry
Pamela Lane

Cal Poly
Tryg Lundquist
Braden Crowe
Eric Nicolai

Commercial Algae Professionals
Albert Vitale
Jeremey Weir

Harmon Consultants
Valerie Harmon

Cellana
Martin Sabarsky
Johanna Anton
Marcela Saracco
David Anton
Emily Knurek
Kate Evans
Reyna Javar
Kari Wolff
Keao Bishop-Yuan
Lynn Griswold
Christina Boyko

Florida Algae
Steven Schlosser
Chris Withstandley
Mary Riddle
Nancy Pham Ho (FIT)

Georgia Tech
Yongsheng Chen
Steven Van Ginkel
Thomas Igou
Yingiang Sun
Zixuan Hu

U.S. DEPARTMENT OF ENERGY

ASU Undergrads
Shaylin Mcghee
Daniel Breyfogle
Levi Bunker
Thomas Chengattu
Delaney DeHertogh
Mark Ford
Riley Greer
Dilon Hurley
Kevin Lawson
Shelby Lui
Carlos Luna
Miguel Martinez
Joe Palaski
Casey Peterson
Jeremy Poet
Alexandra Prassas
Sherry Saethao
Jay Tenison
Jessica Vaughn
Wyatt Western
Mykal Ybarra

GT Undergrads
Fariha Hassan
Jerry Duncan
Frazier Woodruff
Shusuke Doi
Hao Fu
Patricia Penalver-Argueso
Allison Dunbar
Allison Carr
Sichoon Park
Priya Pradeep
Terry Snell
Catherine Achukwu
Christine Yi

CP Undergrads
Aydee Melgar
Gulce Ozturk
Kaitlyn Jones
Michael Antoine
Trung K Tran
Jake Bender
Heather Freed
Daniel McBroom
Michele Hendrickson
Gerard Nguyen
Deven Diliberto
Jack Sunderland
Dan Averbuj
Ann Marie Sequeira
Lauren Miller
Michele Hendrickson
Emily Wang
Jack Sunderland
Ann Marie Sequeira
Soroush Aboutalebi
Lauren Miller
Samantha Lui
Michele Hendrickson
Gabriella Campos
Will Briles
Letty Thottathil

ATP3 partners

AzCATI
Arizona Center for Algae Technology and Innovation

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Sandia National Laboratories

CAL POLY
SAN LUIS OBISPO

UTEX The Culture Collection of Algae
at The University of Texas at Austin

Georgia Tech

cellana
algae-based products for a sustainable future

FLORIDA ALGAE, LLC

COMMERCIAL ALGAE PROFESSIONALS
From Concept to Commercialization

HARMON CONSULTING

Litree立升

EVODOS
DYNAMIC SETTLERS

ASU LightWorks

ASU IRA A. FULTON SCHOOLS OF engineering
ARIZONA STATE UNIVERSITY

U.S. DEPARTMENT OF ENERGY

Goal Statement

Establish a **sustainable network of regional testbeds** that empowers **knowledge creation** and **dissemination** within the algal R&D community, **facilitates innovation**, and **accelerates growth** of the nascent algal biofuels and bioproducts industry.

Outcomes:

- **Increased stakeholder access** to high quality, outdoor cultivation and laboratory facilities
  - Over 40 different testbed clients and >60 completed projects in 4+yrs.
  - Mix of national lab, academic and industrial stakeholders
  - 12 education/training workshops held at 3 ATP^3 sites and 2 additional sites
- **Support DOE**'s techno-economic, sustainability, and resource modeling activities and **close critical knowledge gaps** and inform robust analyses of the **state of technology** for producing algal biofuels and bioproducts
  - ATP^3 cultivation data **the prime source** for 2015 and 2016 BETO SOT
  - ATP^3 has set high data quality standards with 3+ yrs of cultivation data that is completely available to the public
  - Data already seeing use beyond ATP^3 teams and BETO SOT

Quad Chart Overview

Timeline

- **Project start date: 2/1/2013**
  - Pre-Award (at risk) 11/12-1/13
- **Project end date: 12/31/2017**
- **Percent complete: 93%**

Total project cost: $17.05M (DOE Commitment $15M)

- **Function 1: $7.3M**
  - **DOE share: $5.25M**
  - Contractor share: $2.05M
- **Function 2: $9.75**
  - **DOE share: $9.75M**
  - Contractor share: N/A

	FY 12-14 Costs	FY 15 Costs	FY 16 Costs	Total Planned Funding (FY 17-Project End Date
DOE Funded	$5M	$3.2M	$1.8M	$1.9M
Project Cost Share	$1M	$0.32M	$0.64M	$0.085M

Barriers

- **AFt-B** Sustainable Algal Production**: Existing data** on the productivity and environmental effects of biomass feedstock production systems… **are not adequate**
- **AFt-E** Algal Biomass Characterization, Quality, and Monitoring**:** Physical, chemical, biological, and post-harvest physiological variations in harvested algae are not well researched or understood
- **AFt-A** Biomass Availability and Cost: Lack of credible data on potential price, location, seasonality quality, quantity… needed to reduce financial, technical and operational risk.

Partners

ASU (AzCATI) (43%)
National Renewable Energy Laboratory (10%)
Sandia National Laboratories (10%)
Cellana (12%)
Cal-Poly (6%)
Georgia Tech (6%)
Touchstone Research Laboratory (4%)*
UTEX (5%)
Florida Algae (2%)
Commercial Algae Management (2%)

* No longer part of ATP3 as of 8/14/2015

Project Overview

The formation of the Algae Testbed Public-Private Partnership **leveraged** the existing resources at AzCATI and our partner sites. The network represents a **collaboration** of industry, laboratory, and educational facilities across nation. ATP^3 aims to **convene** all algae stakeholders to facilitate opportunities and progress more rapidly to commercialization.

ATP³ Primary Objectives

Strain Identification & Isolation

Biomass Production & Supply

Analytical Services

Education & Training

Equipment Testing

ATP³ offers access to a wide array of services, capabilities and facilities:

Regional testbed facilities for the partnership are physically located in **Arizona, Hawaii, California, Georgia, and Florida.**

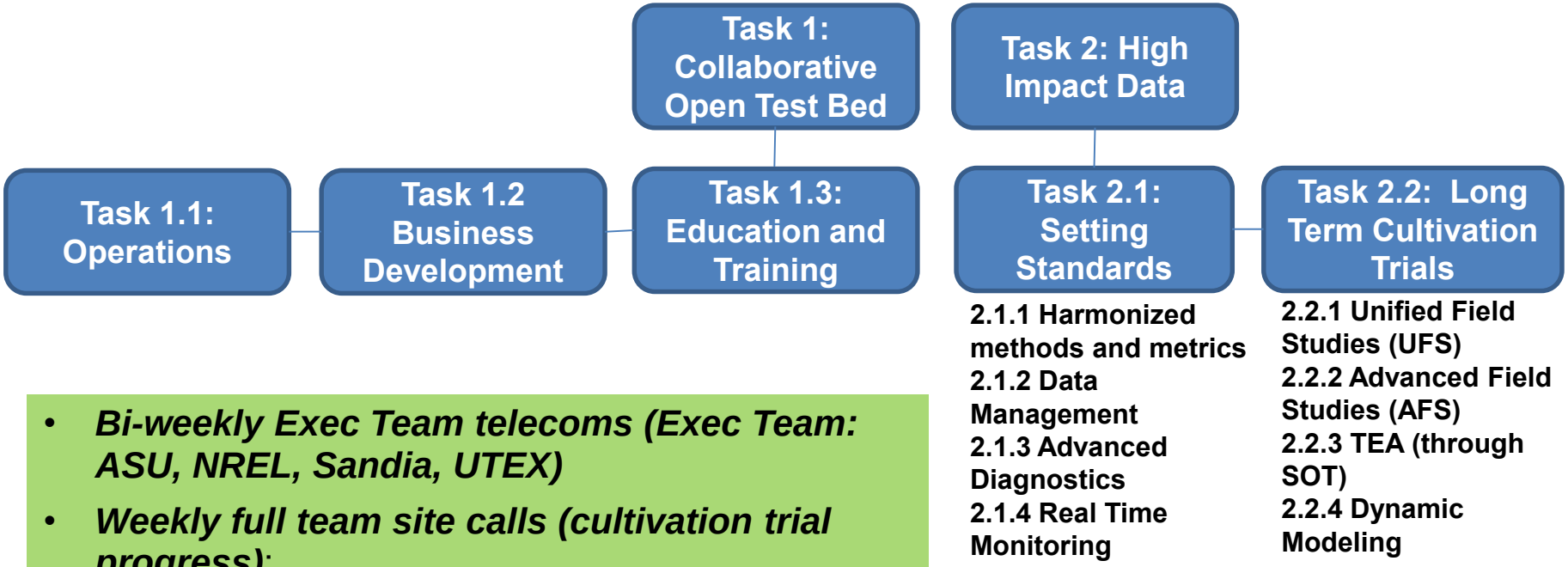
Collaborative Open Testbeds

- Form a national network of testbeds
- Provide increased access to stakeholders
- Share knowledge, learning
- Accelerate R&D outcomes
- Reduce technology and business risk

Collect and Distribute High Impact Data

- Unified research programs
- Pipeline for collection of **high-quality cultivation data** to support algae computational **modeling** including biomass productivity, techno-economic, and life cycle assessment.
- Make data available publicly
- Inform State of Technology (SOT)

Approach: Project Management and WBS



- ***Bi-weekly Exec Team telecoms (Exec Team: ASU, NREL, Sandia, UTEX)***
- ***Weekly full team site calls (cultivation trial progress)***:
- ***Monthly technical presentation webinars***
- ***Quarterly reports/Milestone reports***
- ***Annual all-hands face to face meeting***
- ***Multiple site visits to partner sites by operations lead***
- ***Annual advisory board meetings (Technical and Commercial advisors)***
- ***Ad hoc data review/sharing with UA RAFT and other stakeholders (at least every 6 months)***

Approach: Project Timeline

Phase 1 M1-12

Major Milestones

- ATP organization, **systems and processes established**
- Methodologies **harmonized**
- Initial cultivation trial and **detailed experimental planning completed**

Critical Success Factor:
Network established and experimental framework validated demonstrating readiness to proceed with the long term cultivation trails

Successful Go/No Go February 2014

Phase 2 M13-36

Major Milestones

- Cultivation trials **complete**
- Data made **widely available**
- **State of algal biofuels technology design report** completed (2015)

Critical Success Factor:
Capability of testbed network to **serve stakeholder community** demonstrated

Successful Go/No Go March 2016 (with scope change to extend multisite cultivation trials into Phase 3)

Phase 3 M37-60

Major Milestones

- State of algal biofuels technology **design report updated (2016)**

Critical Success Factor:

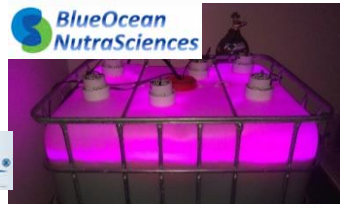
- Value proposition validated and funding secured to **sustain network** in out years
- Requires a robust algal industry seeking access to user facilities and expertise

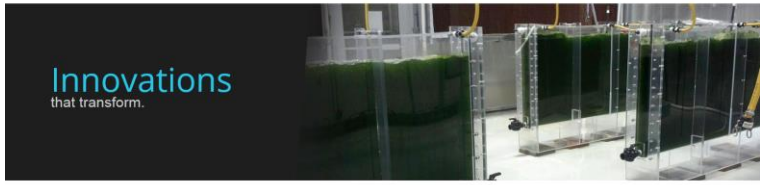
Technical Accomplishments, Progress and Results

ATP3
Algae Testbed
Public-Private Partnership

ATP3: Open for Business

- ***Project Activities***:
  - ✓ biomass supply (1-100's kg)
  - ✓ equipment testing
  - ✓ analytical testing
  - ✓ Culture maintenance and scale up
  - ✓ genetically engineered algae field trials
  - ✓ Education and Training Workshops
- ***Project Benefits***: access to facilities drive technology R&D, de-risk and validate technological innovations
- ***>40 individual clients to date***
- ***>60 completed projects***
- ***>$750K in additional TB revenue***





Education and Training

Education & Training

Demographics of Participants

By Discipline	Count
Academic	59
Industry	50
Government/Labs	16

By Geography	Count
Local	10
US national	71
International	44

Approximately 50% of the participants were students and educators - the majority of these have engineering backgrounds

Less than 30% of participants had exposure to basic lab techniques

- ATP3 has hosted 12 educational workshops to date (~3/yr)
- Over 125 participants
  - add'l~150 engaged through mini-workshops at PSA
- Week-long workshops
  - Over 30 lecture modules
  - Over 15 hands-on field site and laboratory activities
- Demonstrated ability to go **"on the road"**
  - Multiple ATP3 sites (AzCATI/UTEX/NREL) as well as other collaborator sites (LANL/SFCC) utilized
  - Important for future expansion of the E&T program

thealgaefoundation

ATEC ALGAE TECHNOLOGY EDUCATIONAL CONSORTIUM

Open Collaborative Testbed Summary

Major Milestones/Critical Success Factor: Capability of testbed network to **serve stakeholder community** demonstrated

- Simple facilities use/service agreement boilerplate established
- >700 kg of biomass harvested from AFS and customer (toll) projects
  - 160 kg of supplied to Canadian collaborator (for large scale AD studies)
  - ~300 kg supplied into other DOE projects and for researchers
    - Combo of sponsored, direct purchase, toll, and subsidized from 100 g to 60 kg aliquots
- 7 "support projects" which all included direct access to testbeds/equipment/M&S
- 12 E&T 1 week workshops with 125 participants – **established core strategy for supporting workforce development in algae based technology (e.g., in collaboration with ATEC)**
- Key resource for technology benchmarking and validation and thus technology and business risk reduction
- 60 fee-for service projects through CY '16 – including critical projects with national labs for model/lab to field pre-pilot validations (e.g., LANL, NREL, PNNL) completed
  - Additional program income of ~$750K in 4 years - key for supplementing operational expenses of the testbed

High Impact Data:
Long Term Algal Cultivation Trials

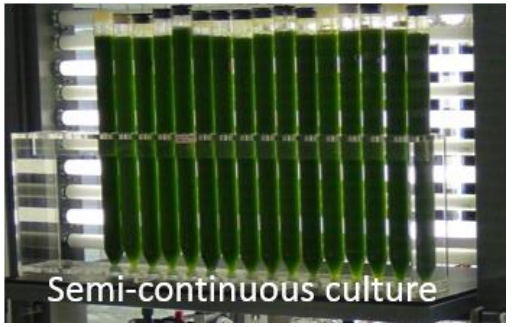
ATP3 set standards and conducted harmonized, rigorous, and objective **long term cultivation trials** to provide a realistic assessment of the **state of technology** for algal based biofuels and bioproducts.

- Our Unified Field Studies (UFS) at the testbed sites along with our Advanced Field Studies (AFS) enabled **comparisons of promising production strains at meaningful scale** across variable conditions
- Our **Scientific Data Management** System and validated, harmonized SOP's for analytical and production processes ensured **data integrity** across all sites
- Our protocols and data from the UFS and AFS are publicly available and provide a critical resource to TEA and LCA analysis yielding **high impact, validated data** http://en.openei.org/wiki/ATP3

Setting Standards – Method Harmonization: Production and Analytical

Challenges to multi-site comparisons…

- Analytical method variation (method, operator skill, etc), can make evaluation of proximate composition across sites challenging.
  - This has a real impact on TEA, LCA and resource assessments uncertainties
- System and scale variation has the potential to induce unwanted, non-geographical related variability between testbeds as a function of:
  - system design
  - scale of operation
  - source water/nutrients
  - sampling protocols
  - productivity measurement protocols
  - operator skill/training/experience/consistency
  - Other…



Mitigation of Site-to-Site Variance

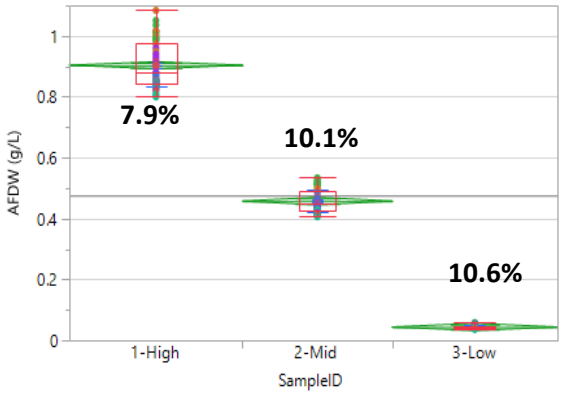
Harmonized Systems via

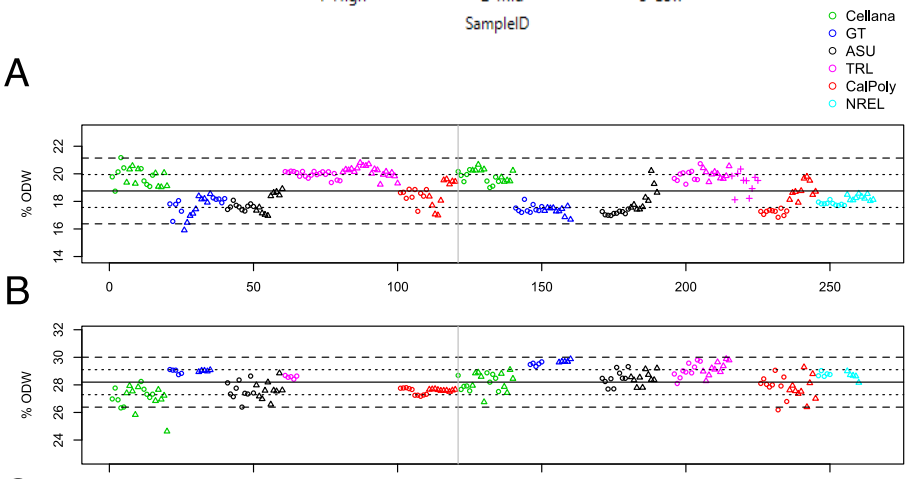
- Uniform design of indoor seed cultivation
- Uniform design of mini-pond system
- Uniform (and automated) water quality monitoring on production units (YSI)
- Uniform light intensity measurements through adoption of same - LiCor LI190 PAR Quantum Sensor (integrated into YSI units)

Harmonized Processes via

- Rigorous verification and validation of analytical and production methodologies
  - Biomass productivity - AFDW, OD, N:P, etc
  - Biomass composition – Ash, Total FAME, Total Protein, Total Carbohydrate
  - Rigorous verification and validation (round robin) framework implemented
- Indoor and outdoor cultivation SOP's (pond cleaning, inoculation, sampling protocols, nutrient adds, transfers/splits),
- Detailed analytical SOP's
- Standardized data reporting in version controlled and locked down spreadsheets with a Scientific Data Management System

Inter-site variance for AFDW

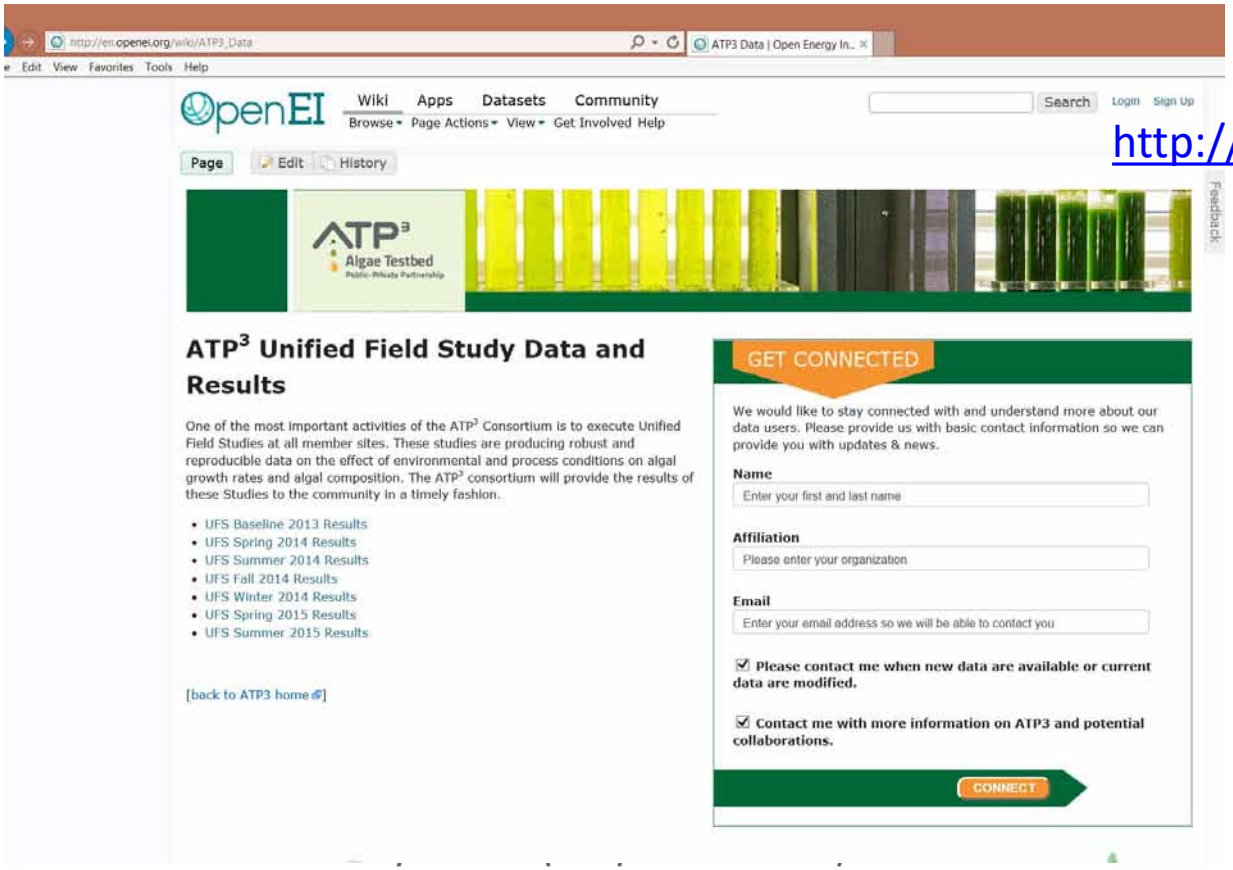




	mean	sd	RSD	*N*
Ash	**18.8**	**1.2**	**6.4**	*237*
Protein	**28.2**	**0.8**	**2.7**	*153*
FAME Lipids	**11.6**	**1.2**	**10.6**	*191*
Carbohydrates	**7.7**	**1**	**12.5**	*198*

The ATP³ Framework: systems, protocols, tools, data, models and projections

ATP³ used a harmonized, experimental framework to implement our Unified Field Studies that enabled comparison of promising strains at a standard system scale across multiple sites. ATP³ developed and implemented a pipeline for the collection and distribution of high-quality cultivation data to support algae computational modeling including biomass productivity, techno-economic, and life cycle assessment and made this data publically available.



http://en.openei.org/wiki/ATP3_Data

Cultivation Study Definitions

- Unified = All testbed sites performing the same experiment in the same systems with the same protocols and strains simultaneously

Standardization of processes and systems was key to executing meaningful multi-site cultivation trials

- Advanced = Sites with various capabilities testing additional production methods and variables to provide data to further enrich the model inputs

Cellana Large Scale Ponds

UFS Strains

UFS Strains (freshwater and marine)

- *Nannochloropsis oceanica* (KA32), supplied by Cellana (marine)
  - Distributed to all sites fall, 2013. Utilized in *"UFSBaseline"* validation for P1 Go/No Go
  - Known to NOT be high productivity but stable and robust cultivar especially for inland sites
  - Critical for initial validation of experimental framework and methods and establishing baseline seasonal/regional performance
- *Chlorella vulgaris, (LRB-AZ-1201) supplied by ASU (freshwater)*
  - Distributed to sites June, 2014, deployed to field Summer 2014
  - Known to be less robust (open pond), but available and importable to HI, high performer in PBR's
- *Desmodesmus* sp. (CO46) supplied by Cellana (freshwater and marine)
  - Basis of Huntley et al 2015 publication
  - Good settling characteristics
  - Range of salinity possible
- Representative cultivars for fuel and high value production (feed, omega-3's)
  - Substantial historical data for both strains (faster project startup)
  - Unencumbered with little restrictions on biomass distribution to third parties (under MTA)
- For the UFS, main operational variables explored included dilution rate/harvest frequency (semi continuous production) and nitrogen source
- Marine strains were all more stable (lower frequency of pond crashes) across the network relative to freshwater strains

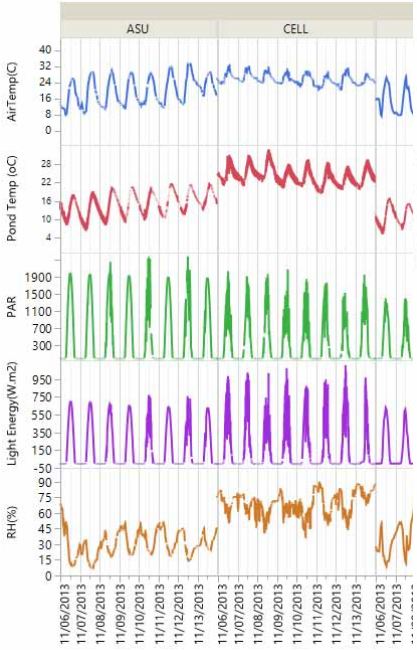
ATP3
Algae Testbed
Public-Private Partnership

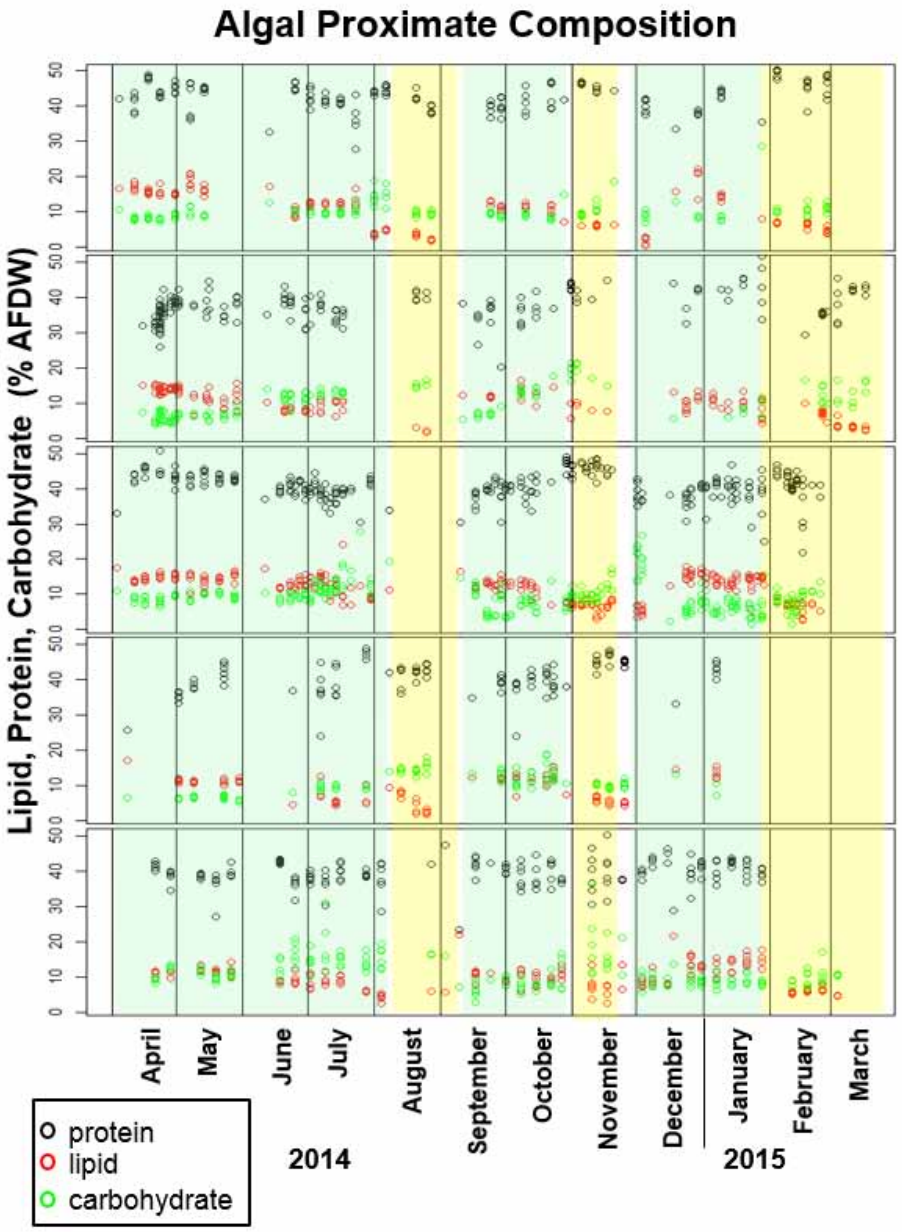
UFS Data Sets

54 coordinated ex

strain	site	2013 Fall	S
N. oceanica KA32	ASU	48.7	
	CP	48.7	
	CELL	25.7	
	FA		
	GT	54.8	
	TRL	47.7	
C. vulgaris LRB-AZ-1201	ASU		
	CP		
	CELL		
	FA		
	GT		
Desmodesmus C046	ASU		
	CP		
	CELL		
	FA		
	GT		

Weather and water qual





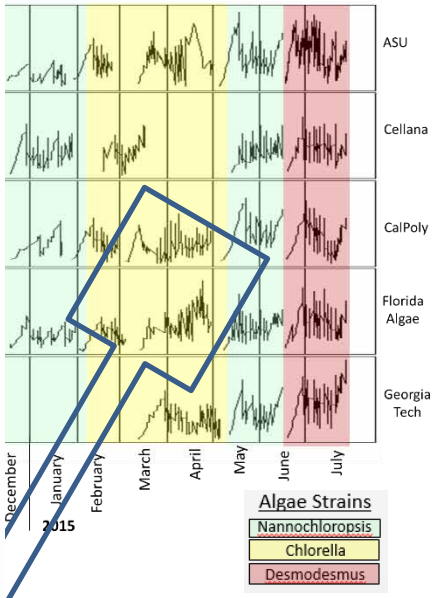
CalPoly

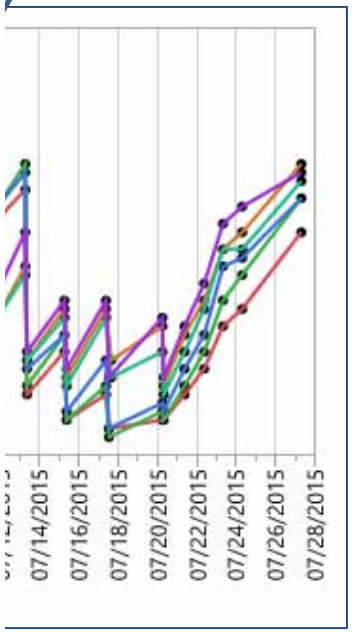
Cellana

ASU

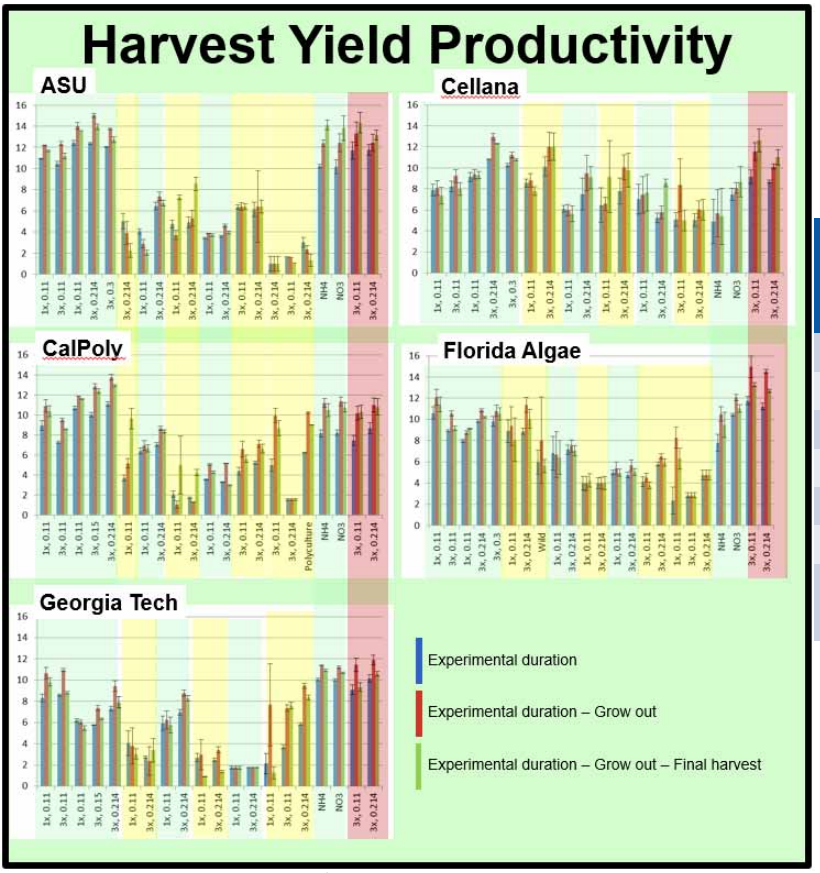
Georgia Tech

Florida Algae





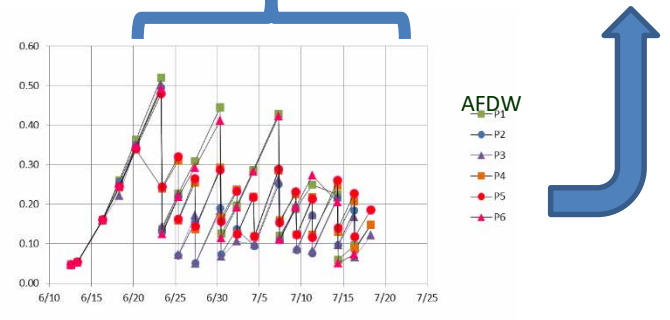
Unified Field Study Productivity: SOT Support



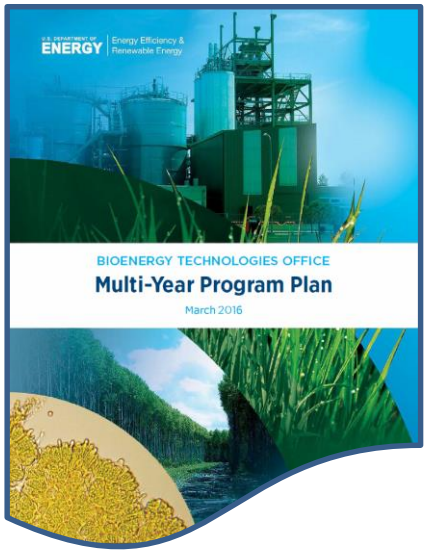
Season	2015 SOT (ATP³)	2016 SOT (ATP³)	2016 SOT (ABY1 Performer)	2020 Projection	2022 Design Case
Summer	10.9	13.3	17.5	27.4	35.0
Spring	11.4	11.1	13.0	22.9	28.5
Fall	6.8	7.0	7.8	19.6	24.9
Winter	5.0	5.0	4.8	9.1	11.7
Average	**8.5**	**9.1**	**10.8**	**19.7**	**25.0**
Max variability	**2.3:1**	**2.7:1**	**3.6:1**	**3:1**	**3:1**
MBSP ($/ton, 2014$)	**$1,227**	**$1,171**	**$1,031**	**$598**	**$494**

ATP3 cultivation data and methods available at: http://www.nrel.gov/docs/fy17osti/67289.pdf

exp dur – grow out



High Impact Data: Informing Current State of Technology

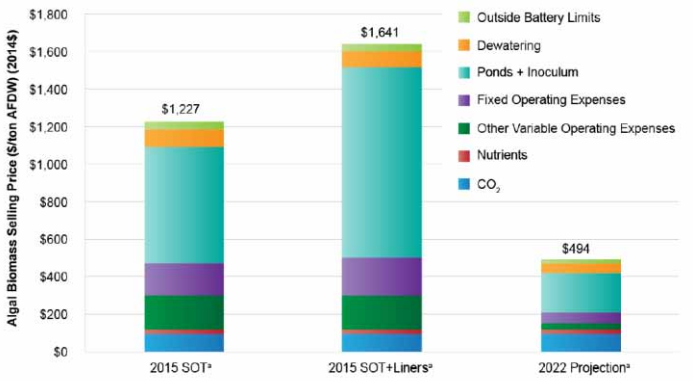


http://www.energy.gov/sites/prod/files/2016/07/f33/mypp_march2016.pdf

Table A-2: Unit Operation Cost Contribution Estimates (2014$) and Technical Projections for Algae Farm[d]

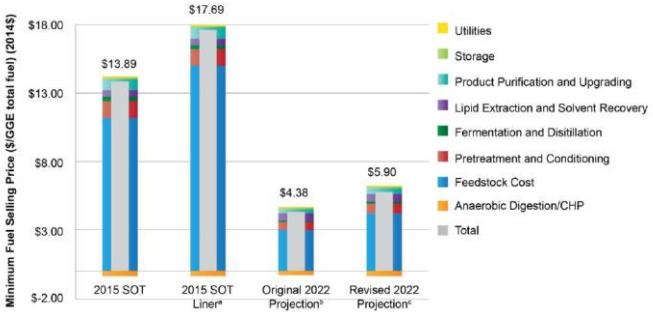
Processing Area Cost Contributions & Key Technical Parameters	Metric	2015 SOT [a]	2015 SOT (Fully Lined) [a]	2022 Projection
Biomass Selling Price	$/ton AFDW	$1227	$1641	$494
Production Cost	$/ton AFDW	$1069	$1483	$409
Harvest/Dewatering Cost	$/ton AFDW	$116	$116	$64
Other Cost (Facility Circulation, Storage)	$/ton AFDW	$42	$42	$21
Gross Biomass Production Yield	ton AFDW/acre-year	12.4	12.4	37.5
Total Farm Power Demand	KWh/ton AFDW	860	860	407
Production				
Total Cost Contribution	$/ton AFDW	$1069	$1483	$409
Capital Cost Contribution	$/ton AFDW	$629	$1015	$213
Operating Cost Contribution	$/ton AFDW	$440	$468	$196
Cultivation Productivity (Annual Average)	g/m^2/day AFDW	8.5	8.5	25
Max Seasonal Production Variability	max:min productivity	2.3:1	2.3:1	3:1
Lipid Content	dry wt% as FAME	27.4%	27.4%	27.4%
N Content	AFDW wt%	1.8%	1.8%	1.8%
CO_2 Utilization Efficiency	% utilized for biomass	90%	90%	90%
Gross CO_2 + Nutrient Cost Contributions[b]	$/ton AFDW	$124	$124	$120
Operating Days Per Year	days/year	330	330	330
Biomass Concentration at Harvest	g/L AFDW	0.27	0.27	0.5
Dewatering				
Total Cost Contribution	$/ton AFDW	$116	$116	$64
Capital Cost Contribution	$/ton AFDW	$93	$93	$52
Operating Cost Contribution	$/ton AFDW	$23	$23	$12
Gross Dewatering Efficiency [c]	%	87%	87%	87%
Net Dewatering Efficiency [c]	%	99%	99%	99%
Final Concentration of Dewatered Biomass	g/L AFDW	200	200	200
Dewatering CAPEX	$/MGD from cultivation	$18	$18	$6
Dewatering OPEX	$/MM gal from cultivation	$4	$4	$1
Balance of Plant				
Total Cost Contribution	$/ton AFDW	$42	$42	$21
Capital Cost Contribution	$/ton AFDW	$31	$31	$15
Operating Cost Contribution	$/ton AFDW	$11	$11	$6

[a] Base case assumes nth-plant facility utilizing low-cost unlined ponds; alternative SOT scenario considers fully lined ponds
[b] Included as part of "operating cost contribution"; gross cost does not account for CO_2/nutrient recycling from conversion



[a] 2015 MBSP projections are derived using cultivation data from the ATP^3 test-bed consortium with 2015 Algae Farm design report assumptions.

Figure 2-16: Cost contribution for algal biomass selling price by process area



[a] 2015 MBSP projections are derived using cultivation data from the ATP^3 test-bed consortium with 2015 Algae Farm design report and 2014 ALU design case assumptions.
[b] Original 2022 projection based on 2014 ALU design report (assumed biomass feedstock)[48]
[c] Revised 2022 projection based on modified ALU design case (modeled biomass feedstock)[49]

Figure 2-17: Cost contribution by process area for CAP Pathway

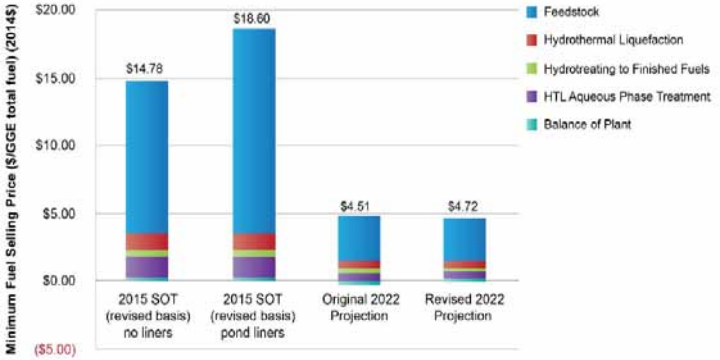


Figure 2-18: Cost contribution by feedstock and conversion process area for HTL Pathway

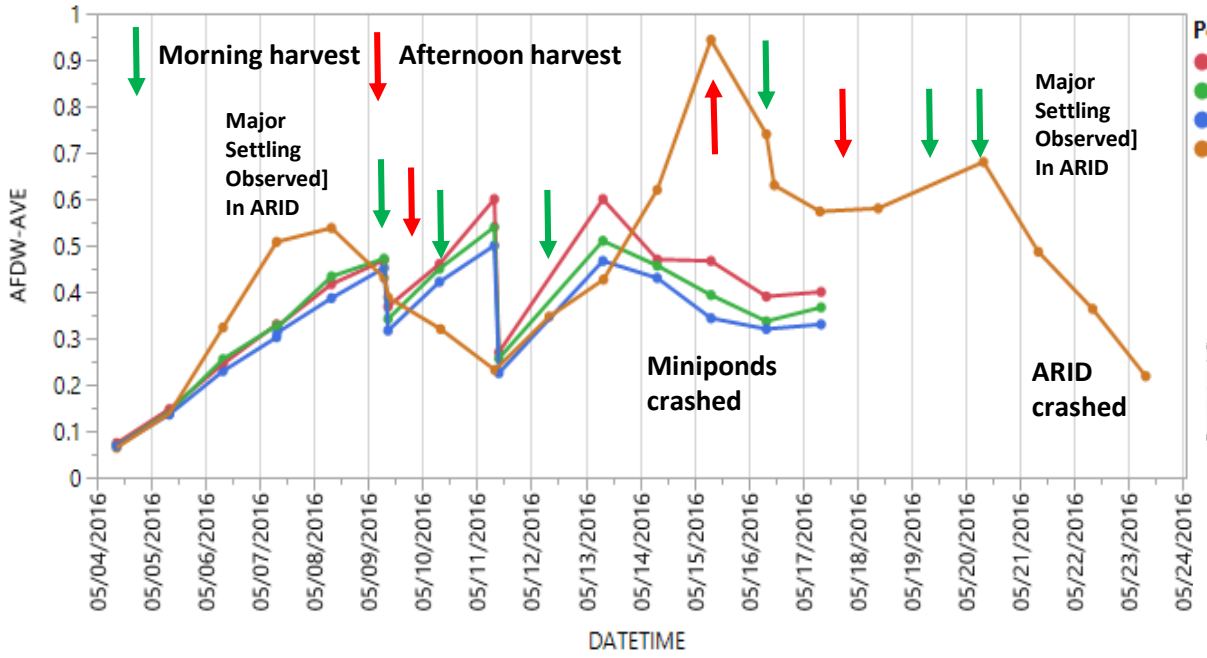
[44] ATP^3 Algae Testbed Public-Private Partnership, http://en.openei.org/wiki/ATP3.
[45] R. Davis, et al. (2015), *Process Design and Economics for the Production of Algal Biomass: Algal Biomass Production in Open Pond Systems and Processing Through Dewatering for Downstream Conversion*, National Renewable Energy Laboratory, NREL/TP-5100-64772, http://www.nrel.gov/docs/fy16osti/64772.pdf.

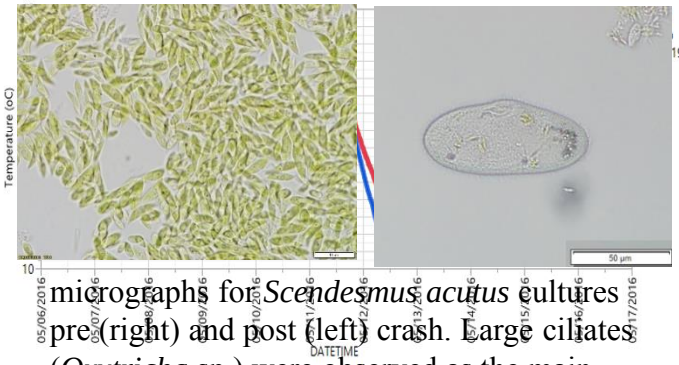
[50] Jones et al. (2014), *Process Design and Economics for the Conversion of Algal Biomass to Hydrocarbons: Whole Algae Hydrothermal Liquefaction and Upgrading*, Pacific Northwest National Laboratory, PNNL- 23227, http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23227.pdf

Advanced Field Studies (AFS)

- Advanced field Studies began late in year 2 and into year 3 of the cultivation trials (and now continue in year 4) and were meant to expand the experimental space and leverage unique assets of the individual sites.
- Additional strains deployed **as planned** in years 2-3 of the cultivation trials – targeting known high performers and expanding into more site specific cultivation trials
  - Polycultures/wastewater, mixing energy (Cal Poly)
  - New marine strains shown to outperform *N. salina* (NREL supplied)
  - *Additional freshwater strains: Scenedesmus* sp., *Kirchneriella* sp. (ASU),
  - *C. sorokiniana* (DOE1230, DOE1228)
  - PBRs/larger scale cultivation
    - Flat panel PBR cultivation (AzCATI)
    - ARID (400 m2) vs ORP's (harvesting, nutrient source) (AZCATI)
    - Mid scale vs. large scale comparisons/2 stage PBR-Pond Batch vs. semi-continuous operation (Cellana)
    - Above include integrated harvesting at pilot scale
- >20 additional experimental data sets that can support the SOT, some of which ran >90 days.

Advanced Field Studies: ARID™ example





micrographs for *Scendesmus acutus* cultures pre (right) and post (left) crash. Large ciliates (*Oxytricha* sp.) were observed as the main grazer leading to crash in all systems.

Harvest Datetime	Harvest ID	AFDW @ Harvest	Volume Harvested (gallons)	Calculated Biomass Removed (g)	Paste Yield (g)	Solids Content (DW)	Harvest Yield (g)	Harvest Effeciency (%)	Harvest Method	Total Ash (%DW)	Total FAME (% AFDW)
5/9/2016 7:00	204	0.43	2400	3906	13309	21.0%	2796	72%	Evodos	6.1	7.9
5/9/2016 16:00	205	0.8	2200	6662	23453	20.8%	4889	73%	Evodos	9.0	7.9
5/10/2016 8:00	206	0.32	2400	2907	43093	15.0%	6464	222%	Evodos	11.0	6.7
5/10/2016 8:00	207	0.32	800	969	40740	17.0%	6926	715%	Evodos	16.0	7.1
5/12/2016 8:00	208	0.35	2200	2914	14681	15.6%	2290	79%	Evodos	9.9	5.9
5/15/2016 16:30	210	0.94	2800	9963	38422	20.7%	7953	80%	Evodos	4.8	8.9
5/16/2016 8:00	211	0.74	2800	7843	29950	22.5%	6739	86%	Evodos	4.8	8.1
5/17/2016 16:30	212	0.8	2400	7267	30477	20.3%	6187	85%	Evodos	4.2	9.2
5/19/2016 8:00	213	0.63	2400	5723	26030	17.3%	4503	79%	Evodos	4.6	8.1
5/20/2016 8:00	N/A	0.68	2500	6435	28000	18.9%	5292	82%	Evodos	19.7	12.0
		Sum	23000	54591	288155		54038				
					avg g/day		4913				
					avg g/m2-day		14.0				

>17 g/m^2-day if harvest efficiency was consistently >90%

ATP3 Relevance

Major Milestones/Critical Success Factors:

- Complete UFS/AFS Cultivation Trials
- Data disseminated to the R&D community
- **State of algal biofuels technology (SOT) supported**
- Capability of testbed network to **serve stakeholder community** demonstrated AND value proposition validated/funding secured to sustain network

ATP3 has established a validated framework for implementing rigorous, long-term multi-site cultivation trials (including GM) and operate as an open collaborative testbed user facility

- At the lead for promoting standards in the industry (Aft-E)
- Allows determination of the effects of regional, seasonal, environmental variation that is to be expected for a national (international) deployment of algae cultivation (Aft-A, B, E)
- Critical validation data source for biomass productivity modeling, TEA, LCA and RA community - allows continued refinement of the current state of technology (SOT) assessments utilized by DOE and the broader industry/investment community (Aft-A,B,E)
- Enabling core AOP projects, competitively funded projects, and industry partners that need access to a validated experimental framework for conducting objective, outdoor cultivation trials with capability for **integrated** pilot-scale operations under real-world environmental conditions (Aft-D,F,G,H,I,J)
- **Integral resource to BETO algae portfolio – actively engaged with 14 out of the 38 projects reviewed this peer review**
- **Established core strategy for supporting workforce development in algae based technology**

ATP^3 Summary

- From 2013 through December 2016, over 75 individual experiments have been conducted across the network with an average duration of at least 40 days
- Major outcomes:
  - Standardized, validated methods with an emphasis on continuous improvement
  - 10 strains utilized in outdoor cultivation experiments with the majority of multi-season data coming from 3 strains with average run time of >40 days
  - Data and experimental protocols for the UFS (Fall 2013 through Summer of 2015) curated and posted on ATP^3's OpenEI.org web portal. http://openei.org/wiki/atp3
  - AFS data sets currently under curation and will be loaded by Q3 2017.
  - ATP^3 generated productivity data **were the primary data sets** supplied to the DOE sponsored SOT reports for 2015, 2016 and will be for 2017
  - Data beginning to be used by outside groups
  - Strong E&T program that is well recognized as a key resource to the stakeholder community
- Novel platforms for pond ecology monitoring and real-time monitoring of culture density and health, demonstrating ATP^3's capability for deploying new technology into an active R&D pilot facility
- Novel methodology developed to quantify pond reliability metrics - a nascent idea in the research community but key to long term deployment and viability
- While overall customer base remains challenging for sustainably supporting a test bed network without ongoing federal support – ATP^3 has demonstrated the ability to work collaboratively across the algal value chain

Supplemental Slides

Future work

- Complete AFS cultivation work in support of FY17 SOT (data reduction and analysis)
  - Experimentation extended through FY17 end (AzCATI only)
  - Update data on OpenEI.org
  - Complete publications on UFS/AFS work (4 publications, 3 in review, 6+ manuscripts in progress)
  - E&T workshops continue through CY 2017
  - Engagement with ATEC on curriculum development continues
- Ongoing marketing of the testbed network to the stakeholder community providing services, open access, and setting standards
  - Includes discussions with major funding agencies (DOE/USDA, etc) for FY18 (and beyond) SOT support
  - **Integral resource to lab AOP program and the broader BETO algae portfolio – actively engaged with 14 out of the 38 projects reviewed this peer review**

Publications and Presentations

Publications

1. Gharagozloo, P. E., Drewry, J. L., Collins, A. M., Dempster, T. A., Chris V. Choi, C. V., and S. C. James. Analysis and modeling of *Nannochloropsis* growth in lab, pond, and raceway experiments. 2104. *J. Appl. Phyc*. Online edition © Springer Science+Business Media Dordrecht February 2014 DOI 10.1007/s10811-014-0257-y. 12 pp
2. Park, S., Van Ginkel, S.W., Pradeep, P, Igou, T., Yi, C., Snell, T., Chen, Yongsheng. (2014) "The selective use of hypochlorite to prevent pond crashes for algae-biofuel production". *Water Environment Federation*. Accepted.
3. Igou, T., Van Ginkel, S.W., Penalver-Argueso, P., Fu, H., Doi, S., Narode, A., Cheruvu, S., Zhang, Q., Hassan, F., Woodruff, F., Chen, Y. S., (2014), "Effect of Centrifugation on Water Recycling and Algal Growth to Enable Algae Biodiesel Production", Water Environment Research, 86 (12): 2334-2338
4. Wang, J., Rosov, T., Wensel, P., McGowen, J., Curtiss, W. "A preliminary implementation of metabolic-based pH control to reduce CO2 usage in outdoor flat-panel photobioreactor cultivation of *Nannochloropsis oceanica* microalgae." Algal Research, 18: 288-295. DOI:10.1016/j.algal.2016.07.001
5. Knoshaug, E.P., Wolfrum, E., Laurens,L., Pienkos, P., Dempster, T., McGowen, J. "Open Pond Algal Cultivation Datasets of the Algae Testbed Public-Private Partnership (ATP3): Unified Field Studies" submitted (2017)
6. Laurens, L., Van Wychen, S., Pienkos, P., Harmon, V., and McGowen, J. "Harmonization of Experimental Approach and Data Collection to Streamline Analysis of Biomass Composition from Algae in an Inter-Laboratory Setting" submitted to Algal Research submitted to Algal Research (2017)
7. McGowen, J., Knoshaug, E., Laurens, L., Dempster, T., Pienkos, P., Wolfrum, E., Harmon, V. "The Algae Testbed Public-Private Partnership (ATP3) Framework; Establishment of a National Network of Testbed Sites to Support Sustainable Algae Production" submitted to Algal Research (2017)

Presentations:

1. "An Overview of a Successful Algae Testbed Model: Arizona Center for Algae Technology and Innovation (AzCATI) and the Algae Testbed Public-Private Partnership (ATP^3) at Arizona State University". Thomas A. Dempster, Consortium de Recherches et Innovations en Bioprocedes Industriels au Quebec (CRIBIQ), Sherbrooke, Quebec, October 2012.
2. ATP^3 BETO Project Peer Review, Washington DC, May 2013.
3. "Validated Algae Growth Model and Optimization Study." **Patricia Gharagozloo** and Jessica Drewry. 3rd International Algal Biomass, Biofuels and Bioproducts Conference June 2013.
4. "Pulsed Electric Field (PEF) Processing of Microalgae and Related Activities at Arizona Center for Algae Technology and Innovation (AzCATI) at ASU", Thomas A. Dempster, Bioelectrics Symposium 2013; Karlsruhe, Germany; September 2013.
5. "The Algae Testbed Public Private Partnership -ATP^3" Ron Pate. Algae Biomass Organization, Algae Biomass Summit, Orlando, FL, October 2013.
6. "Composition of Algal Biomass for Biofuels and Bioproducts: High Impact Data and Method Harmonization" **L. Laurens**, E. J. Wolfrum, T. Dempster, J. McGowen, P.T. Pienkos, Algae Biomass Organization, Algae Biomass Summit, Orlando, FL, October 2013.
7. "An Experimental Framework for Performing Long Term Cultivation Trials Across Different Regional, Seasonal, Environmental, and Operational Conditions" John A. McGowen, Bio Pacific Rim Summit, San Diego (December 11th, 2013).

Publications and Presentations

9. "Method Harmonization Efforts for Microalgae Production and Biomass Analyses at Arizona State University's Arizona Center for Algae Technology and Innovation (AzCATI) and the Algae Testbed Public-Private Partnership (ATP^3)" Thomas A. Dempster, 28th Congress of the Phycological Society of Southern Africa, Melkbosstrand, South Africa, January 2014.
10. "Algae Testbed Public Private Partnership (ATP^3): Multi-Region, Long-Term Algae Biomass Cultivation Trials" John A. McGowen, Bio World Congress on Industrial Biotechnology, May 2014.
11. "Overview of Innovative Algae Cultivation Modeling, Diagnostics, and Standardized Analytics Available Through DOE's National Algae Testbed Project – ATP^3" **Philip T. Pienkos,** Ron Pate, John McGowen, Todd Lane, Tricia Gharagozloo, Tom Reichardt, and Lieve Laurens, Symposium of Biotechnology for Fuels and Chemicals, Orlando, FL, May 2014.
12. "Modeling of *Nannochloropsis* sp. Growth in Algae Testbed Unified Field Studies" Patricia Gharagozloo, 5th Congress of the International Society for Applied Phycology, Sydney, Australia, June 25, 2014.
13. "Long term cultivation studies a the Algae Testbed Public-Private Partnership: Preliminary data from the Unified Field Studies" **Philp T. Pienkos**, Valerie Harmon, John McGowen, 4th International Conference on Algal Biofuels, Biomass and Bioproducts (ABBB), Sante Fe, NM, June 2014.
14. "Spectroradiometric monitoring for biomass measurement and predator detection in *Nannochloropsis* sp. cultures." **T. A. Reichardt**, A. M. Collins, J. A Timlin, T. A. Dempster, and J. A. McGowen, 4th International Conference on Algal Biofuels, Biomass and Bioproducts (ABBB), Sante Fe, NM, June 2014.
15. "Driving towards a common language for characterization of algal biomass for biofuels and bioproducts: High impact data and method harmonization," **L. Laurens**, J. McGowen, T. Dempster, P.T. Pienkos, 4th International Conference on Algal Biofuels, Biomass and Bioproducts (ABBB), Sante Fe, NM, June 2014.
16. "Driving towards a Common Language for Algal Biomass for Biofuels and Bioproducts: High Impact of Data and Method Harmonization **L. Laurens**, J. McGowen, T. Dempster, P.T. Pienkos, Algae Biomass Organization, Algae Biomass Summit, San Diego, CA October 2014.
17. "Algae Testbed Public Private Partnership (ATP3): Education and Training Workshops Offer Extensive Hands-On Learning Opportunities" T. Dempster, M. Sommerfeld, S. Manning, Jerry Brand, Poster Presentation, Algae Biomass Organization, Algae Biomass Summit, San Diego, CA October 2014.
18. "Performance Evaluation of the Helix™ Tubular Glass Photobioreactor for High Quality Inoculum Production" **J. A. McGowen**, T. A. Dempster, T. Rosov, and D. Cardello, Algae Biomass Organization, Algae Biomass Summit, San Diego, CA October 2014.
19. "Long Term Cultivation Studies at the Algae Testbed Public Private Partnership: Spring and Summer Season Data Update from the Unified Field Studies" J. McGowen, T. Dempster, P. Pienkos, V. Harmon, Poster Presentation, Algae Biomass Organization, Algae Biomass Summit, San Diego, CA October 2014.
20. "Algae Testbed Public Private Partnership (ATP3): Opportunities to Engage in Open Collaborative Testbed Network Activities" **T. Dempster**, J. McGowen, Algae Biomass Organization, Algae Biomass Summit, San Diego, CA October 2014.
21. "Progress and Perspectives of Large Scale Algae Biomass Harvesting: A Case Study at the ATP3 Testbed" **X. Zhang**, J. McGowen, Q. Hu, M. Sommerfeld, Algae Biomass Organization, Algae Biomass Summit, San Diego, CA October 2014.
22. "Modeling and Optimization of Nannochloropsis oceanica Growth in Seasonal Algae Testbed Unified Field Studies" P.E. Gharagozloo, J. L. Drewry, and T.A. Dempster, Poster Presentation, Algae Biomass Organization, Algae Biomass Summit, San Diego, CA October 2014.
23. "Long Term Cultivation Studies at the Algae Testbed Public Private Partnership (ATP^3): Spring and Summer Season Data Update from the Unified Field Studies". **J. McGowen**, T. Dempster, P. Pienkos, V. Harmon, 3rd Asia-Oceania Algae Innovation Summit, Daejeon, Korea, November 2014.

Publications and Presentations

24. "Enabling Algal Technology development at the Algae Testbed Public Private Partnership (ATP^3): J. McGowen, T. Dempster, **P. Pienkos**, L. Laurens, 3rd Asia-Oceania Algae Innovation Summit, Daejeon, Korea, November 2014. (Invited Talk)
25. "Algae Testbed Public Private Partnership (ATP^3): Enabling Algal Technology Research and Development." **J. McGowen**, BIO Pacific Rim Conference, San Diego, CA, December 2014.
26. P. Pienkos chaired a session at the Pacific Rim BIO Conference in December entitled, "Algae Testbeds: Models for Accelerating Commercialization." The panel included representatives of four algae testbeds: AlgaeParc in The Netherlands, the Algae Testbed Public-Private Partnership (ATP^3) and the Regional Algal Feedstock Testbed (RAFT) in the US, and the Algae Industry Incubation Consortium (AIIC) in Japan.
27. BETO Algae Platform Peer Review, March 25, 2015, Washington DC.
28. "Pond Crashes: Evaluation of ATP^3 Unified Field Study Results to Identify the Primary Factors Affecting Pond Reliability" V. Harmon, **J. McGowen**, T. Lane, E. Knoshaug, T. Dempster, B. Crowe, T. Igou, C. Withstandley, P. Pienkos, 5th International Conference on Algal Biomass, Biofuels, and Bioproducts, June 10th, 2015., San Diego, CA.
29. "Harmonized algal cultivation experiments in the Unified Field Studies: The first year of yield and productivity data from the ATP^3 testbed consortium." **E. Knoshaug**, L. Laurens, V. Harmon, T. Dempster, P. Pienkos, and J. McGowen, 5th International Conference on Algal Biomass, Biofuels, and Bioproducts, June 10th, 2015, San Diego, CA.
30. "Large-Scale Cultivation of Nannochloropsis sp. microalgae on Recycled Water and Harvesting with Centrifugation and Membrane Filtration." **P. Wensel**, J. McGowen, 5th International Conference on Algal Biomass, Biofuels, and Bioproducts, June 9th, 2015, Sand Diego, CA.
31. "Dynamic composition of Nannochloropsis sp. biomass with an emphasis on high-value omega-3 fatty acids." **L. Laurens,** E. Knoshaug, V. Harmon, E. Wolfrum, P. Pienkos, J. McGowen, 5th International Conference on Algal Biomass, Biofuels, and Bioproducts, June 9th, 2015, Sand Diego, CA.
32. "Harvesting Optimization Study for *Nannochloropsis oceanica* for Multiple Seasons and Locations" P. Gharagozloo, Poster Presentation, 5th International Conference on Algal Biomass, Biofuels, and Bioproducts, June 9th, 2015, Sand Diego, CA.
33. "Genetic Evaluation of Pond Crashes During ATP^3 Unified Filed Studies" T. Lane, K. Poorey, D. Curtiss, H. Geng, Poster Presentation, 5th International Conference on Algal Biomass, Biofuels, and Bioproducts, June 9th, 2015, Sand Diego, CA.
34. "ATP^3: A Collaborative Network for Algae Technology Commercial Development" **J. McGowen,** TechConnect World Innovation Conference and Expo, June 15th, 2015, Washington DC.
35. "Algae Testbed Public Private Partnership (ATP^3): Opportunities to Engage in Open Collaborative Testbed Network Activities" **T. A. Dempster** and J. McGowen, 29th Congress of the Phycology Society of Southern Africa, June 23rd, 2015, St. Lucia, South Africa.
36. "MALDI-TOF MS as a Tool for Taxonomic Discrimination and Identification of Economically Significant Microalgae Strains" **T. A. Dempster**, H. Gerken, D.L. Barbano, R. Diaz, L. Zhang, and T.R. Sandrin. 29th Congress of the Phycology Society of Southern Africa, June 23rd, 2015.
37. "ATP^3: A Collaborative Network for Algae Technology Commercial Development" **J. McGowen**, Bioenergy 2015, June 24th,, 2015, Washington DC.
38. "How ATP^3 is Addressing the Challenges of Scale-up in Algae Technology R&D" **J. McGowen**, Bioenergy 2015, June 24th,, 2015, Washington DC.
39. "Genetic Evaluation of Pond Crashes During the ATP3 Unified Field Study", **Poorey, Kunal**, Deanna J. Curtis, Haifeng Geng, Kelly P. Williams, and Todd W. Lane. ABO Summit, Sep 30 - Oct 2, 2015 Washington, DC.
40. "Genetic Evaluation of Pond Crashes During the ATP3 Unified Field Study", **Poorey, Kunal**, Deanna J. Curtis, Haifeng Geng, Kelly P. Williams, and Todd W. Lane. ABO Summit, Sep 30 - Oct 2, 2015 Washington, DC.
41. "Large-Scale and Long-Term Cultivation and Harvesting of *Nannochloropsis* sp. and *Scenedesmus acutus* Microalgae", **P. Wensel**, J. McGowen, T. Dempster, Poster Presentation ABO Summit, Sep 30 - Oct 2, 2015 Washington, DC.

Publications and Presentations

42. "ATP^3 Unified Field Studies: Primary Factors Driving Pond Crashes and Management Strategies in Open Ponds" **V. Harmon**, J. McGowen, P. Pienkos, T. Lane, E. Knoshaug, T. Dempster, B. Crowe, T. Igou, C. Withstandley, M. Saracco, ABO Summit, Sep 30 - Oct 2, 2015 Washington, DC.
43. "Long Term Cultivation Studies at the Algae Testbed Public Private Partnership (ATP^3): Results over one year of Unified Field Studies (UFS)" **B. Crowe**, V. Harmon, J. McGowen, P. Pienkos, T. Lane, E. Knoshaug, T. Dempster, T. Igou, C. Withstandley, M. Saracco, ABO Summit, Sep 30 - Oct 2, 2015 Washington, DC.
44. "The Arizona Center for Algae Technology and Innovation (AzCATI) and the DOE funded Algae Testbed Public Private Partnership (ATP^3)" **J. McGowen.** Invited talk, International Symposium on Algae Biomass (ISAB 2015), University of Tsukuba Algae Biomass Energy System R&D Center (ABES), Tokyo, Japan. November 16-17th, 2015.
45. "Algae Technology Development Progress: Algae Testbed Public Private Partnership Progress and Research Results" Panel Discussion on ATP^3 progress to date. Moderated by **J. McGowen**, with presentations from **T. Dempster, V. Harmon, L. Laurens, K. Poorey.** Bio World Congress on Industrial Biotechnology, San Diego, CA, April 17th-20th, 2016.
46. "Algae Testbed Public Private Partnership: Two Years of Unified Field Study Results to Identify Current State of Technology for Algal Biomass Production." **J. McGowen** TechConnect World Innovation Conference and Expo, Washington, DC. May 22nd-25th, 2016.
47. "The Algae Testbed Public Private Partnership (ATP3): A Platform for Engagement and Access to Industry, National Lab, and Academic Expertise, and World-class Algal R&D Facilities" **J. McGowen.** Invited talk, Algal Biomass, Biofuels and Bioproducts 6th International Conference, San Diego, CA, June 26th-29th, 2016.
48. "Seasonal and geospatial variation in algal biomass productivity; measured values from the field" **Hutton, M.** Algal Biomass, Biofuels and Bioproducts 6th International Conference, San Diego, CA, June 26th-29th, 2016.
49. "Capturing pond crash signature of atp^3 unified field study using machine learning on 16s amplicon sequencing" **Poorey, K.** Algal Biomass, Biofuels and Bioproducts 6th International Conference, San Diego, CA, June 26th-29th, 2016.
50. "Spectroradiometric monitoring for early warning detection of pond crash conditions" **Reichardt, T.A.** Algal Biomass, Biofuels and Bioproducts 6th International Conference, San Diego, CA, June 26th-29th, 2016.
51. "Settled algae return to promote reliable bioflocculation in wastewater grown algae" **Swain, C.L.** Algal Biomass, Biofuels and Bioproducts 6th International Conference, San Diego, CA, June 26th-29th, 2016.
52. "Large-scale cultivation and de-watering of microalgae using novel vacuum airlift (VAL) system, membrane filtration, and centrifugation **Wensel, P.** Algal Biomass, Biofuels and Bioproducts 6th International Conference, San Diego, CA, June 26th-29th, 2016.
53. "Dynamic composition of the alga Nannochloropsis sp. at five geographical location sites over the course of a full year outdoor production" **Laurens, L.** *Algal Biomass, Biofuels and Bioproducts 6th International Conference, San Diego, CA, June 26th-29th, 2016.*
54. "Identification, characterization, and development of deployable halotolerant algal strains." **Guarnieri, M.T.** *Algal Biomass, Biofuels and Bioproducts 6th International Conference, San Diego, CA, June 26th-29th, 2016.*
55. "The Algae Testbed Public Private Partnership (ATP3): The challenges and rewards of integrated lab to pilot-scale cultivation and downstream processing as demonstrated through ATP^3" **McGowen, J.** *AOAIS 2016, Wuhan China, September 18-20th, 2016.*

Responses to previous comments

ATP3 has established **a solid foundation** for future work in this area. The round robin testing and unified protocols and equipment provide an improved view of environmental factors…

> ATP3 **represents the backbone** of the DOE portfolio and represents a singular achievement in standardizing the metrics and methods with which to measure progress.

This is a most welcome addition to the program. I expect it to be **worth the investment** as it is used by more and more people. I look forward to **seeing genetically modified organisms** being used, with the accompanying regulatory requirements. BETO should fund this project for several years to give time for academia and small companies to develop strains and species that are worthy of the reproducibility that this project can deliver.

Though the project **needs to find a viable path to support itself should DOE funding run out,** so far it appears to be a success. The long-term cultivation trials are also providing a community service by working to standardize protocols and provide robust realistic data sets to the field to assist R&D and modeling efforts….

> Overall, this approach offers unique testing **capabilities to early stage projects and provides expertise and technical assistance for enhancing project outcomes**…Success of this project will benefit the state of technology and improve the viability of commercial bioenergy applications throughout many regions and climates.

New Impressions of ATP3 from current stakeholders

"AzCATI's expertise, facilities, analysis capabilities, and ability to provide algae biomass across a breadth of strains, have been absolutely critical to our success."
- Diversified Technologies

"There are many claims that one technology or innovation is better than another or that one strain outperforms another. We have found that often these claims have a degree of internal bias that is skewed by those trying to sell or develop the technology, strain, method, etc. The ATP3 test site at ASU/AzCATI gives us the actual side by side parameters that have helped determine what actually works and what is hype." – Commercial Algae Professionals

"ATP3, through its commitment to high quality data has championed the work of the ABV to establish robust, reproducible, and accurate analytical methodologies. Through its incorporation of these methodologies into its standard practices, ATP3 has helped to set the bar for all other research groups in the BETO portfolio." - NREL Collaborator

"ASU/AzCATI has been able to thrive providing algae cultivation testing service to the industry with remarkable testing facility. This facility offers one of the only unbiased independent locations with adequate technology, personnel and know how to sort thru the multitude of claims and hype prevalent in the industry and drill down to actual quantifiable data that can be benchmarked. All this happened because the funding of DoE through ATP3 program" -- --Morgan Hill Bioenergy

New Impressions of ATP³ from current stakeholders

Workshop Testimonials

I've returned with a great feeling in my heart. What a fantastic learning/growing experience. (University Professor, Alberta, Canada)

I highly recommend this workshop for anyone at any level involved in algae projects. The instructors focused their presentations toward the appropriate level of the participant's technical knowledge to provide the highest value of learning. The flow of this workshop was excellent and the logistics were perfectly coordinated. This was the best and most valuable workshop that I have ever attended on behalf of my lab. (National Lab Employee, Colorado, USA)

Many thanks for an excellent workshop experience. It was absolutely clear that a great deal of pre-planning and coordination were required to make the workshop run so smoothly at both of the New Mexico locations. The participation of SFCC and LANL was outstanding and every tour, lecture, lab experience and networking event provided a tremendous opportunity for learning and promoting algae. I really appreciate your attention to detail, your organization, and your attitude. (Industry Executive, Hawaii, USA)

Highly instructive and interesting workshop. I especially enjoyed your bioproducts module. Thanks for your intellectual, yet light and fun approach to teaching. (National Lab Employee, New Mexico, USA)

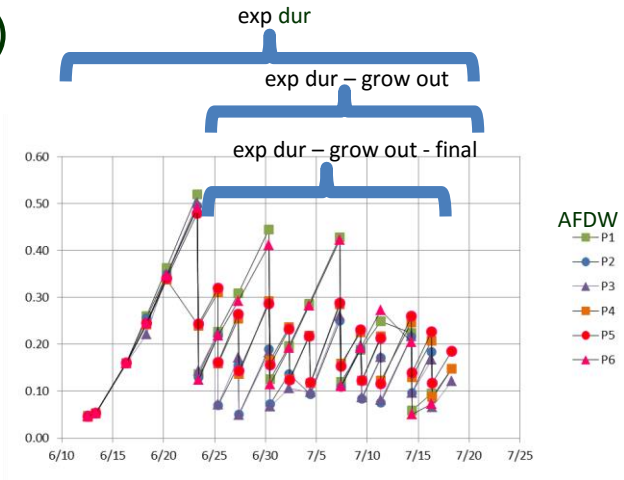
Spring 2016 workshop was superb! Thank you. I literally didn't have a chance to waste even a minute between the time I got off the plane on Monday and until I got back on the plane on Friday. The schedule was well planned out, instructors were extremely knowledgeable and open to answer all the questions I had. I wish all the training workshops that I've attended were organized in the same fashion. This kind of workshop is very important for the algae industry for people and companies that are just starting out and for those that have a ton of experience in the industry. (Industry Representative, California, USA)

I was blown away by how open and willing to help were the instructors. They definitely were not just going by the script; their passion for what they do was evident during every session. I learned a lot. (Industry Representative, California, USA)

I was very impressed with the comprehensive information I received, the valuable networking opportunities, and the overall organization of the event. I appreciate your willingness to share your knowledge, expertise, and resources with others - it is such a valuable quality and will allow for huge gains within the field. Additionally, I loved the fact that the workshop participants included a diverse array of individuals from industry, research, and education. This greatly added to the richness and collective knowledge of the group and allowed for the formation of important connections and novel ideas. I'm excited to use the knowledge and expertise I've gained to establish a thriving algae lab on my campus to introduce students to algae research and the exciting potential of algae to solve many of our current and future world challenges. The workshop greatly exceeded my expectations.
(Community College Instructor, California, USA)

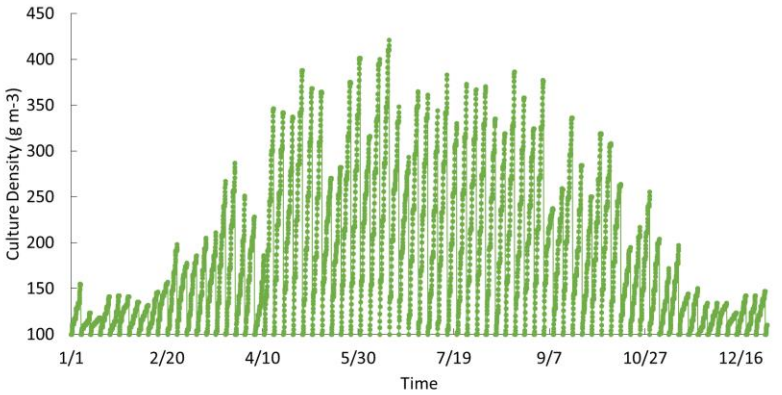
Unified Field Study Productivity

- **Calculation**
  - Harvested yield productivity (harvested biomass (g)/ 4.2 (m^2)/ elapsed time (days)
  - Different from daily changes in AFDW (biological) productivity
- **Calculated over three time ranges**
  - Entire experimental duration (exp dur)
    - Day of inoculation to day of final harvest
  - Without initial grow out (exp dur – growout)
    - Grow out to 0.5 g/L AFDW (1-2 weeks)
  - Without initial grow out and final harvest (exp dur – growout – final)
    - During semi-continuous operation
- **Data fed to TEA/LCA for DOE SOT assessments**

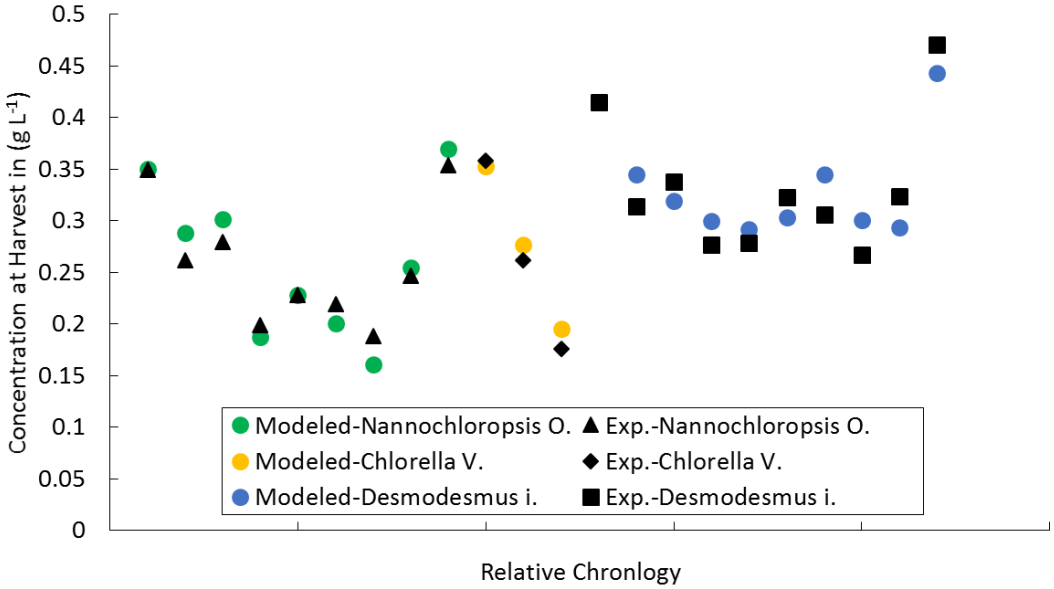


CSU Growth Modeling Validation: Example of external stakeholder using ATP3 Data

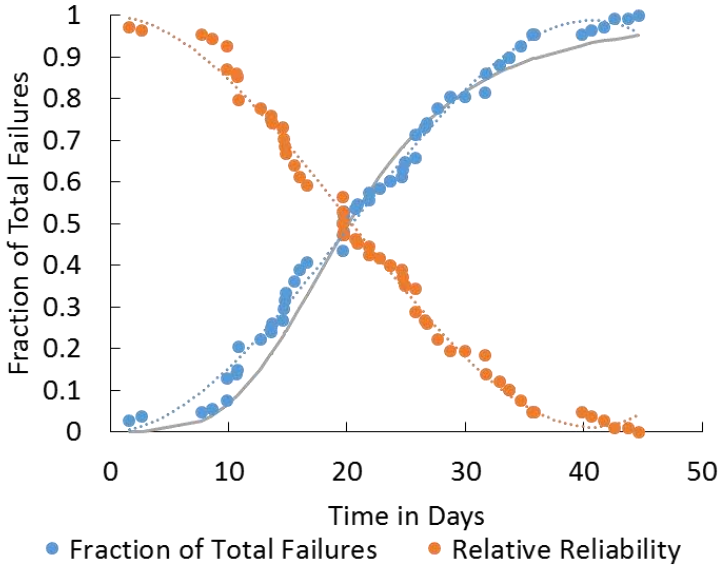
- Validation of a growth model approach for PBRs to ORPs
- Approach successfully applied to *Galdieria s.Nannochloropsis oceanica, Desmodesmus I, and Chlorella V.*
- Stochastic model of culture crashes fit to full ATP3 dataset



ORP Productivity- 1 year



Validation Plot for 2 different species

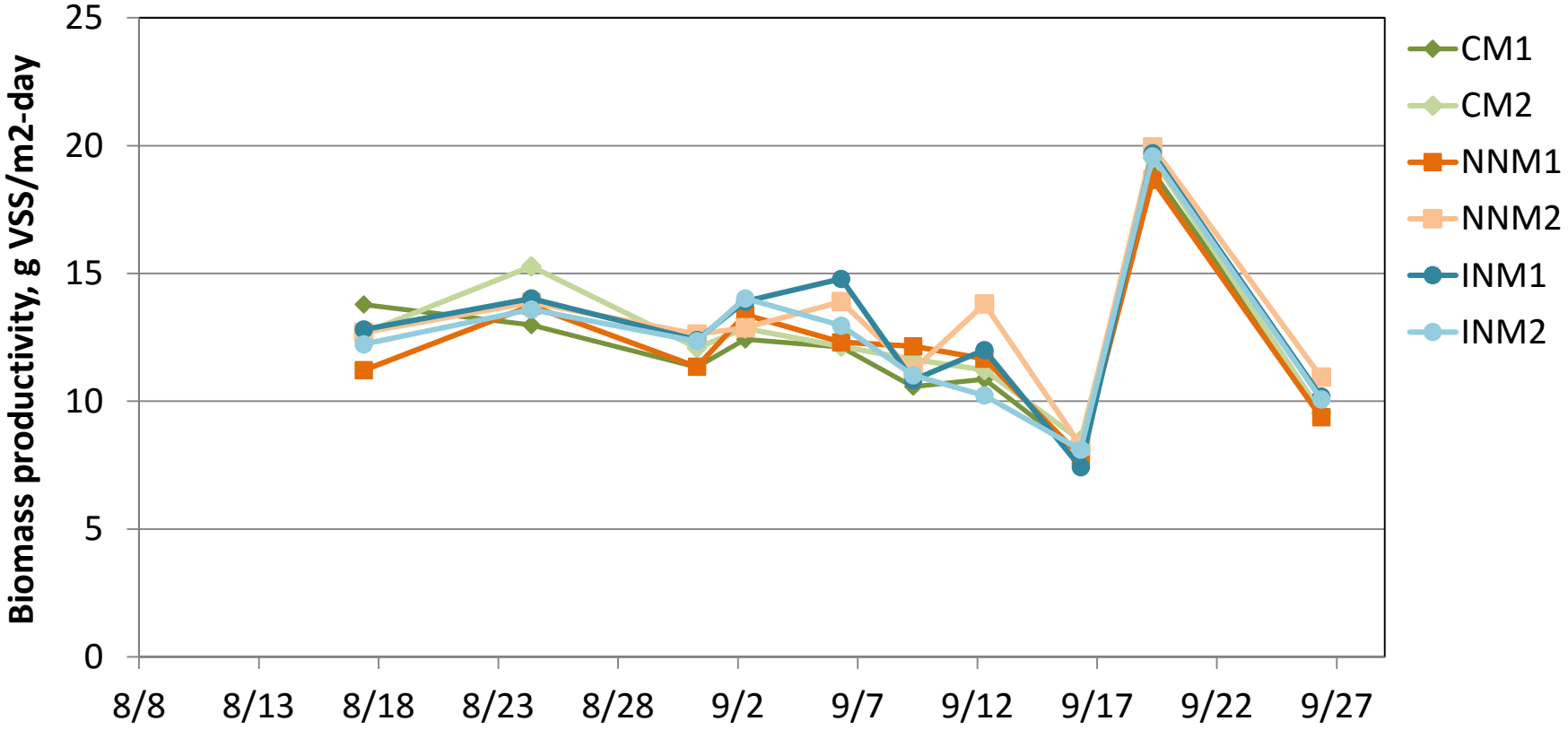


Culture Failure Modeling

Jason.Quinn@colostate.edu

CalPoly Fall2016 AFS: Paddlewheel mixing

- Looked at effects of different paddlewheel operational scenarios (continuous (CM), off at night (NNM) and intermittent at night (INM)
- Consistent ~12 g VSS/m2-day achieved, regardless of treatment (polyculture)
- Productivity unaffected when with no or intermittent nighttime mixing



Potential reduction in operating costs of ~15%

CalPoly Fall2016 AFS:
Slurry return – effect on sedimentaiton

Enriched gravity sedimentation explored for low-cost harvesting
Consistent 90% settling achieved, at no reduction in productivity